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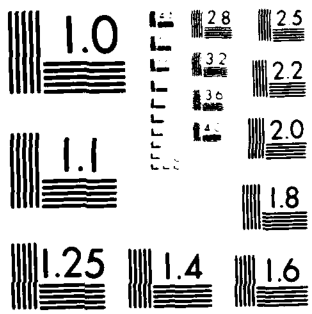

MICROCOPY RESOLUTION TEST CHART

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Report OEHL 81-32

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SOME THOUGHTS ABOUT INDUSTRIAL HYGIENE SAMPLING STRATEGIES, LONG-TERM AVERAGE EXPOSURES, AND DAILY EXPOSURES

Approved for public release; distribution unlimited

USAF Occupational and Environmental Health Laboratory
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

This technical report has been reviewed and is approved for publication.

William E Mabson
WILLIAM E. MABSON, Colonel, USAF, BSC
Commander

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This paper, an extension of earlier results presented to the 1979 American Industrial Hygiene Conference (Chicago 1979) and to the Second American Chemical Congress (Las Vegas 1980), expands upon the concept of comparing decision criteria by comparing their decision probabilities in representative workplaces. The earlier papers compared the decision probabilities of the National Institutes of Occupational Safety and Health (NIOSH) action level criteria with those of the legal action level criteria, as embodies in the Occupational Safety and Health (OSHA) standards completion project; with those of the compliance

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criteria from the OSHA Industrial Hygiene Field Operations Manual; and with those of the NIOSH sampling strategy as an example of the performance of a Markov decision process. These earlier results are reviewed to show the existence of workplaces which are likely to be declared acceptable by the legal action level criteria, but are nevertheless subject to citations from conscientious compliance officers.

The earlier work introduced a new term; the Average Exposure Limit (AEL). The AEL was defined as a boundary for separating the probably acceptable workplaces from those which are clearly unacceptable. In this paper, the AEL is reinterpreted as a standard against which one evaluates long-term average exposure, making it somewhat analogous to the Permissible Exposure Limit (PEL) against which one evaluates daily exposures. By properly selecting the relationship between the AEL and an existing PEL, it may be possible to create an easily interpreted standard which could be used to support the National Academy of Science Emergency Exposure Limits (EEL) and to provide guidance to professional industrial hygienists in place of the now discarded American Conference of Governmental Industrial Hygienists (ACGIH) excursion factors. This possibility will be emphasized by charts showing the fraction of daily exposures which are allowed to exceed the PEL as a function of the value chosen for the AEL.

Because this presentation is designed to stimulate creative thinking about the problems of setting and enforcing standards, it more closely resembles an interim progress report than a legislative proposal.

This was paper #20
Presented to 1981 American Industrial Hygiene Conference by J.C. Rock
Portland, Oregon.
General Industrial Hygiene Session
Tuesday, 8:40 a.m., May 26, 1981

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Glossary of Terms

ACGIH: The American Conference of Governmental Industrial Hygienists

AL: The action level or decision threshold such that if a measurement x' exceeds the AL one may reject the null hypothesis (95% confidence used to derive AL for this report). Otherwise accept the null hypothesis.

AEL: The average exposure limit. For chemicals posing only a chronic health hazard a workplace may be assumed to be OK if the long term average exposure x remains below the AEL.

AEL AL: The decision threshold used to test for the null hypothesis that the long term average exposure is less than the average exposure limit.

e: The fraction of exposures which exceed the standard.

GM: The geometric mean of the population of all possible exposures. This is larger than the geometric mean of the population of all possible measurements (Ref 2).

GSD: The geometric standard deviation of the population of all possible exposures. This is smaller than the geometric standard deviation of the population of all possible measurements (Ref 2).

LEGAL AL: The decision threshold specified in some recent OSHA standards such that if a measurement x' exceeds the LEGAL AL it is presumed that unmeasured exposures x occasionally exceed the permissible exposure limit.

MPE: The maximum probable exposure is that exposure which is likely to occur no more than 1 day out of a typical 250 days per working year.

NIOSH: The National Institute of Occupational Safety & Health, a research organization under the Federal Department of Health & Human Services.

NIOSH AL: The decision threshold used to test for the null hypothesis that no more than 5% of an employee's exposures exceed the permissible exposure limit.

NOK: The decision one makes when an exposure measurement exceeds the upper action level. This does not necessarily mean the workplace is hazardous, only that the hypothesis that the workplace is unacceptable was accepted at a specified level of confidence.

OK: The decision one makes when an exposure measurement is less than the action level. This does not necessarily mean the workplace is safe, only that the null hypothesis (defined in Table 2) was accepted at a specified level of confidence.

OSHA: The Occupational Safety & Health Administration. An enforcement agency of the Federal Department of Health & Human Services.

OSHA AL: The decision threshold used to test for the null hypothesis that the true exposure x underlying the observed measurement x' was less than the permissible exposure limit.

pdf(x): The probability density function. The probability that the random variable x has a value between a and b equals the area under the curve y = pdf(x) between a and b.

PEL: Permissible Exposure Limit. Legally defined in the OSHA Act. Used here generically to represent an airborne concentration which is tolerable for a specified period of time. Thus, both a duration and a concentration must be specified.

TLV: Threshold Limit Value. The registered trademark of the ACGIH for the workplace exposure limits which are revised and published annually in a small pamphlet commonly called the TLV Booklet.

TWA: The average value of an exposure. The average must be taken over a period equal to that specified in the applicable PEL, typically 5, 15, 30 minutes or 8 hours. TWA is not observable (see definition of x).

UAL: The Upper Action Level or decision threshold defined such that if a measurement x' exceeds the UAL the hypothesis that the workplace is unacceptable is accepted at a specified level of confidence. If the measurement is less than the UAL that hypothesis is rejected.

x: The normalized exposure, which is equal to the true worker exposure divided by the permissible exposure limit. This random variable is not observable, since the process of making a measurement is itself a random process.

x': The normalized exposure measurement calculated by dividing the measured concentration by the permissible exposure limit. The measurement must be based on a sample collected over the period of time specified in the PEL. This random variable represents the best possible estimate of true exposure during the measurement period.

$\bar{x}$: The arithmetic average of all representative exposures. This is distinctly different from the average of exposure measurements $\bar{x}'$ (Ref 2).

INTRODUCTION:

We believe that the primary objective of an industrial hygiene program is to provide a safe and healthful work environment for every employee. Thus, a significant portion of the formal training of an industrial hygienist should be directed to learning the difference between an acceptable and an unacceptable work environment. This involves studying toxicology, epidemiology, engineering controls, personal protective equipment, and sampling methods for evaluating the condition of the workplace. Sampling has purposefully been placed last in this list because it is an after-the-fact event which merely serves to document exposures and does not, by itself, contribute to the welfare of employees. However, the decisions currently being made on the basis of environmental sampling reveal what sort of protection we in the industrial hygiene profession believe to be adequate, and therefore tend to quantify a frequently used but ill-defined term: professional judgement. This is an elusive question which the authors have been pursuing for three years.

Our approach has been to utilize the NIOSH model of workplace exposures to find out which workplaces are declared acceptable by the various decision strategies currently in use. To bring you up-to-date on our progress, we first introduce the NIOSH model of workplace exposures and use it to identify a group of workplaces which we believe to be unacceptable. We will then review the concept of an action level and generalize it to include the OSHA compliance decision as well as the original NIOSH action level and the Legal action level. In addition, we introduce a new action level based on a concept we call the Average Exposure Limit. We show that statistically derived action level criteria used to interpret one measurement are very conservative in that they accept only the best of workplaces, while more practical criteria are too lenient in that they accept workplaces which industrial hygienists would generally agree to be unacceptable. Finally, we show two decision strategies which utilize more than one measurement in making their decisions and which tend to be so arbitrarily conservative that they reject a large number of workplaces which intrinsically meet the requirements of the null hypothesis they purport to test.

THE MODEL OF OCCUPATIONAL EXPOSURES:

The model we use has two primary features: a normalized exposure variable, x, and a lognormal probability density function, pdf(x). The use of a normalized exposure allows the model to apply to any occupational hazard. One merely divides the actual time weighted average (TWA) exposure by the applicable permissible exposure limit (PEL) to create this normalized exposure ($x = TWA/PEL$). Note that whenever $x > 1.0$, the exposure exceeded the standard. It is not certain that occupational exposures are lognormally distributed, but they are certainly represented by a skewed distribution with properties similar to those of the lognormal distribution: there are no negative exposures, most exposures are small, and there are occasional large exposures.

The great advantage of the lognormal exposure model is that each employee's work environment can be completely described by two parameters. The geometric standard deviation (GSD), which measures the variability of exposures, is one of these parameters. Any of the common industrial hygiene estimates of the cleanliness of a work environment may be used for the other parameter: GM, $\bar{x}$, e, or MPE. The median exposure is the geometric mean (GM); the long-term average exposure is the arithmetic average, $\bar{x}$; the fraction of exposures which exceed the standard equals the probability that an exposure exceeds the standard, $e = P(x > 1)$; and the maximum probable exposure, MPE, is defined for purposes of this paper as that exposure which is not exceeded more than once a year, $P(x > MPE) = 1/250$. Recall that a typical working year includes 250 workdays.

Figure 1 shows the distribution of exposures in nine different workplaces and illustrates the behavior of the long-term average exposure as a function of e and GSD (Ref 1). Values of e close to zero correspond to relatively

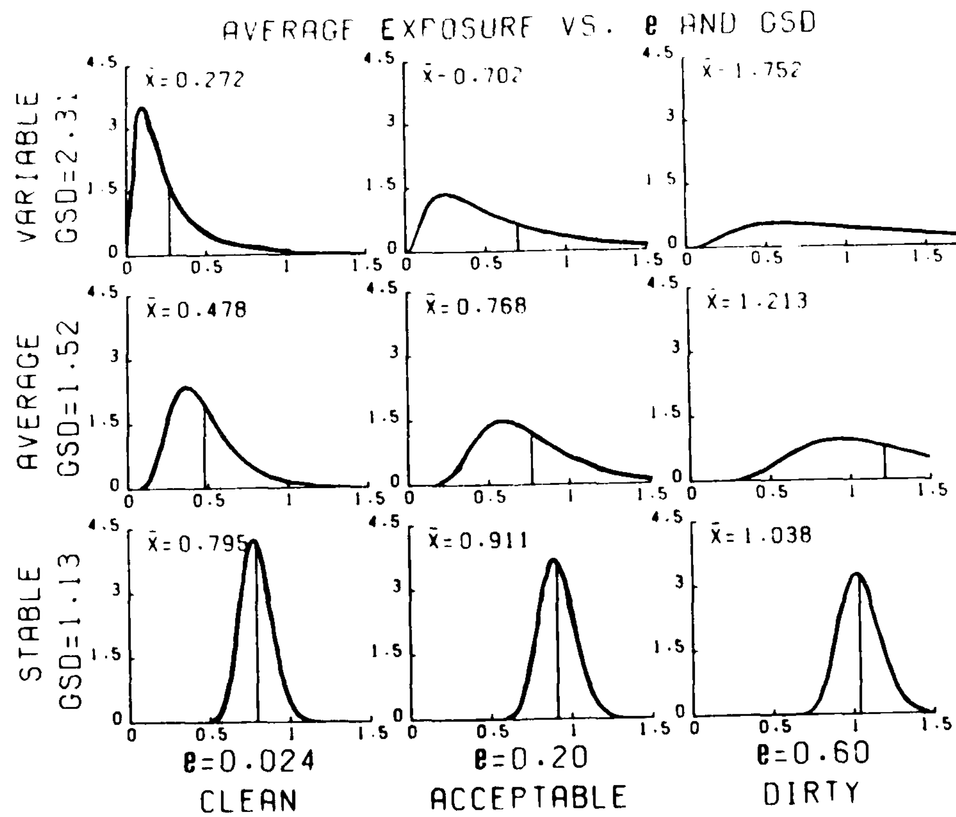

Figure 1. Probability density function for nine different workplaces showing $\bar{x}$, the long-term average exposure as a function of e, the fraction of exposures which exceed the standard and GSD, the geometric standard deviation of the exposures.

clean workplaces (only a small fraction of exposures exceed the standard) while values of e near one correspond to dirty workplaces (nearly all exposures exceed the standard). Values of GSD near one correspond to very stable workplaces (where all exposures are approximately equal), while values of GSD greater than 2 correspond to work environments similar to those experienced by firefighters or emergency maintenance workers (where both very large and very small exposures are common). The primary purpose of Figure 1 is to clarify and emphasize that each pair of values (e, GSD) specify a unique workplace with a well defined distribution of exposures. The secondary purpose is to show that the long-term average exposure, $\bar{x}$, is a function of both e and GSD, and to provide a frame of reference for other Figures.

Figure 2 is a contour plot of the long-term average exposure as a function of e and GSD. The nine "+" signs mark the locations of the nine sample workplaces plotted in Figure 1. Each point in the e, GSD plane represents one unique workplace, and the value of its long-term average exposure can be determined by interpolation between the contours. Each contour is labelled with the value of $\bar{x}$. We should all be able to agree that any workplace where the long-term average exposure exceeds the standard is

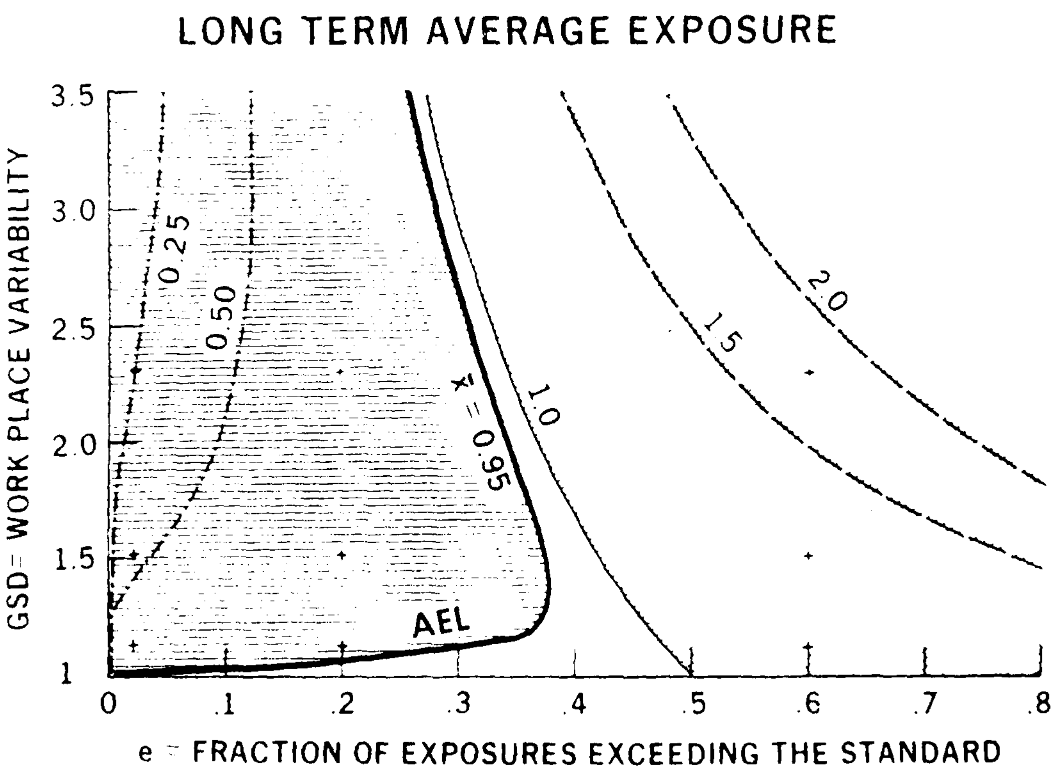

Figure 2. Contour plot of $\bar{x}$, the long-term average exposure, as a function of e and GSD. Each "+" marks the location of one of the workplaces from Figure 1.

unacceptable. This region is shaded with diagonal lines. The heavy contour where $\bar{x}$ = 95% of the standard is labelled the average exposure limit (AEL). This is an arbitrary selection which may be applicable for some kinds of occupational exposures. It seems easier to find agreement on clearly unacceptable workplaces than on acceptable workplaces, so rather than ask you to believe that all workplaces in the horizontally shaded area are acceptable, we ask you to believe that all other workplaces are unacceptable. Note that these criteria reject three of the nine workplaces from Figure 1.

Figure 3 shows the contours for the maximum probable exposure (MPE). This is the exposure we expect to be exceeded one day out of a typical 250 day working year (Ref 8). That is, P(x > MPE) = .004. The old ACGIH excursion factors suggested that a transient peak exposure during a workshift should never exceed 3 times the TLV, in the least dangerous situations. Therefore, there should be no objection to the concept that all workplaces with an MPE greater than 4 times the standard will be considered to be unacceptable, especially since the MPE refers to a full period measurement rather than to an excursion which occurs during a period when the TWA exposure is less than the standard. Note that the MPE exceeds 4 in only two of the nine workplaces (marked by "+") from Figure 1.

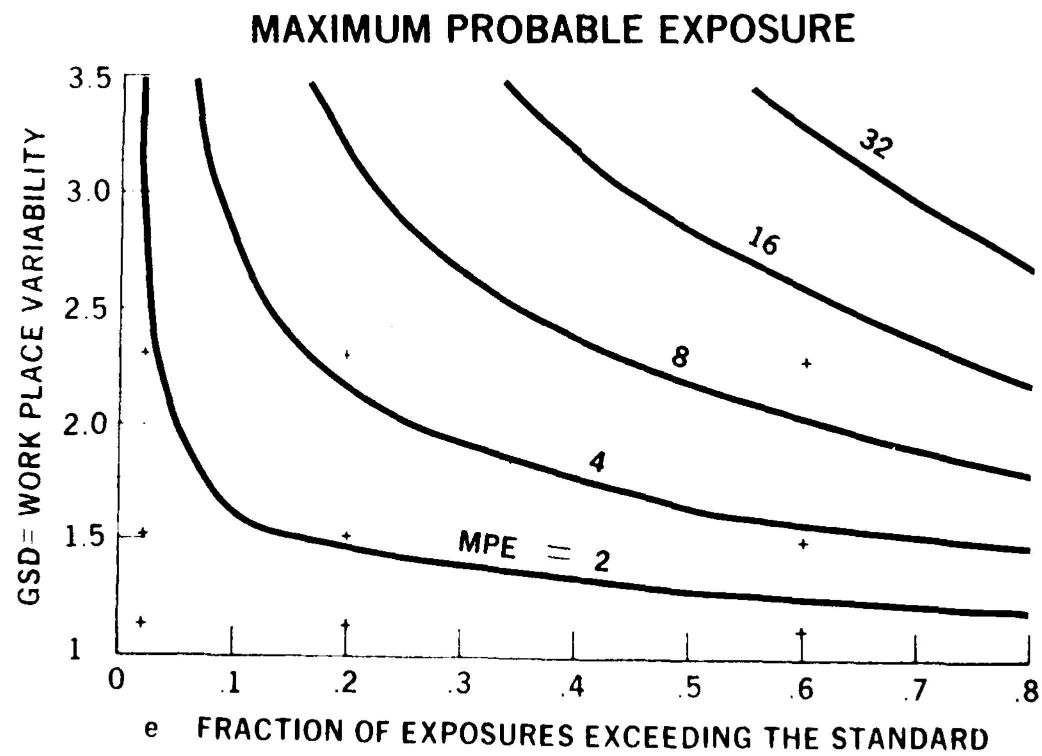

Figure 3. Contour plot of MPE, the maximum probable exposure, as a function of e and GSD. Each "+" marks the location of one of the workplaces from Figure 1.

Figure 4 shows the workplaces which are rejected in either Figure 2 or Figure 3. If you are designing engineering controls for an occupational hazard, you should never design a system which will result in an exposure distribution lying in this region. Figure 4 is introduced here to serve as an absolute frame of reference to be used to judge the quality of decisions made by various decision strategies. At this point in our development we still have no grounds for deciding what is acceptable, only that certain workplaces are clearly unacceptable.

GENERALIZED ACTION LEVEL DECISION CRITERIA:

An action level is needed because the measurements of a typical industrial hygiene survey are only estimates of exposures. The uncertainty of the environmental sampling and analytical chemistry processes cause the distribution of measurements to be broader than the distribution of exposures. Measurements are available to decision makers, but exposures are

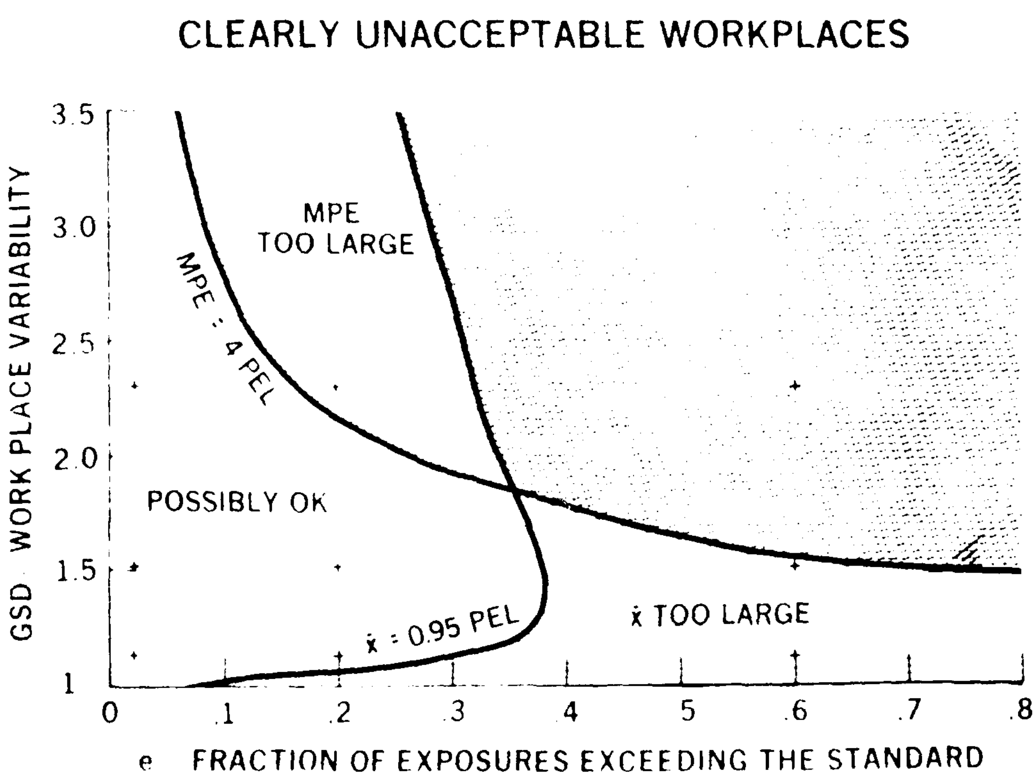

Figure 4. Contours showing workplaces which are clearly unacceptable, either because the maximum probable exposure (MPE) is greater than four times the permissible exposure limit (PEL), or because $\bar{x}$, the long-term average exposure is greater than 95% of the PEL.

not. Thus, it is necessary to distinguish between exposures which are expressed by the normalized variable x, and measurements which are expressed by the normalized variable x'. It has been shown elsewhere (Ref 1) that just as there is a unique distribution pdf(x) of employee exposures, there is also a unique distribution of employee exposure measurements pdf(x') associated with each workplace (e,GSD). The detailed mathematical descriptions of pdf(x) and pdf(x') have been published previously (Ref 2).

The generalized action level decision criteria are a set of two null hypotheses and two decision thresholds. One hypothesis describes the condition which we call OK; it is associated with the decision threshold called the action level, AL. The other null hypothesis describes the condition which we call NOK (or NOT OK); it is associated with the decision threshold called the upper action level, UAL. To make a decision, one compares the value of a measurement, x', with both the AL and the UAL. If $x' > AL$ one rejects the hypothesis that the work environment is OK. If $x' < UAL$ one rejects the hypothesis that the work environment is NOK. Table 1 summarizes the decision probabilities. Note that P indicates the probability that the indicated decision is made or that the indicated event occurred.

Table 1

Generalized Action Level Decision Probabilities

$$P(OK) = P(x' \leq AL)$$

$$P(NOK) = P(x' > UAL)$$

$$P(?) = P(AL < x' \leq UAL)$$

There are three possible outcomes from the generalized decision criteria: accept one hypothesis and decide the workplace is OK, accept the other hypothesis and decide the workplace is NOK, or reject both hypotheses and make no decision (?).

The four decision criteria we discuss differ in the definition of their null hypotheses and therefore in the value assigned to their two decision thresholds. Due to the scope of this paper, we focus primarily on the action level and the null hypothesis associated with the decision that a workplace is OK. We do not discuss in detail the upper action level. Figure 5 shows the value of the action level for the four decision criteria of interest, and Table 2 summarizes the null hypotheses.

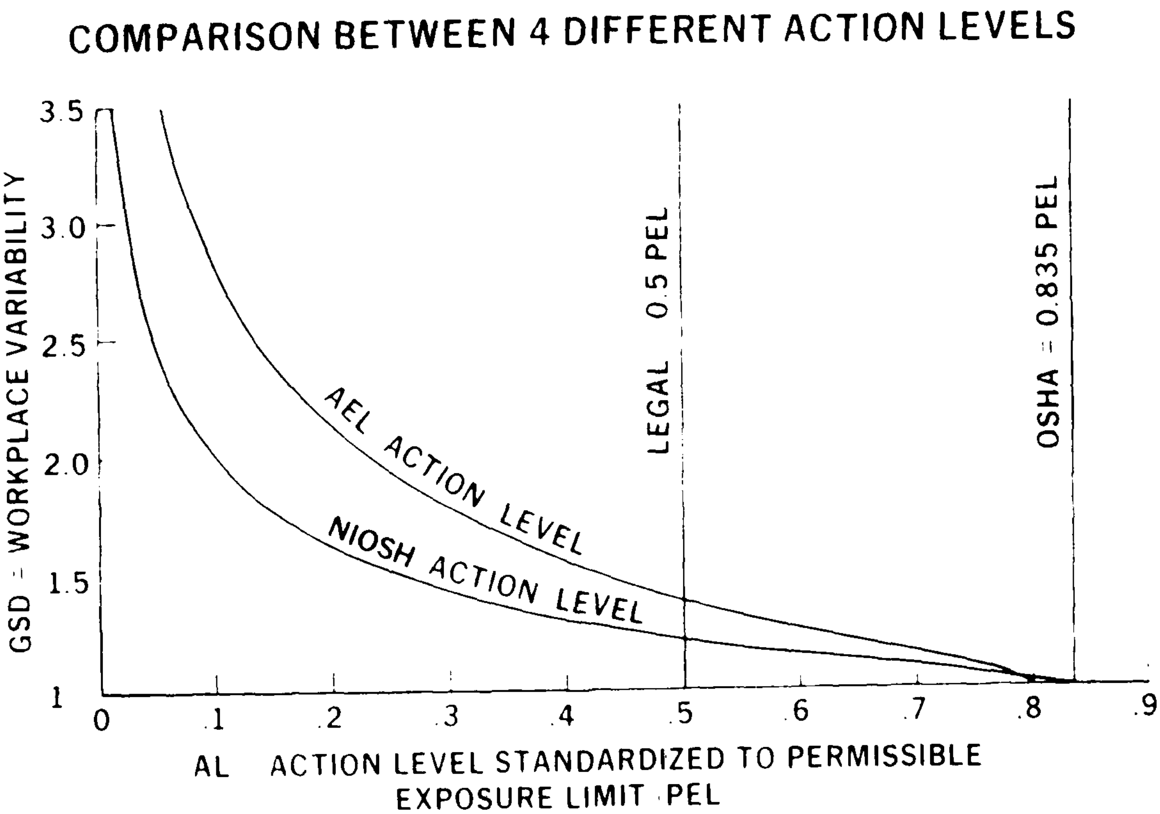

Figure 5. Four different action levels plotted as a function of the geometric standard deviation (GSD) and normalized (or standardized) to the PEL (the horizontal axis reads in units of AL/PEL).

Table 2

Summary of Null Hypotheses
for
Decision Criteria Compared in this Paper

CRITERIA	NULL HYPOTHESIS	If $x' > AL$, then:
OSHA	exposure is no larger than the standard	$P(x > 1.0) \geq 0.05$
LEGAL	unknown, but possibly that exposure is no larger than 60% of standard	unknown, possibly $P(x > 0.6) \geq 0.05$
NIOSH	less than 5% of exposures exceed the standard	$P(e \geq 0.05) \geq 0.05$
AEL	long-term average exposure is less than 95% of standard	$P(\bar{x} > 0.95) \geq 0.05$

The OSHA criteria is easiest to understand. The null hypothesis is that the measurement represents an exposure which was no larger than the standard. Thus, the AL is derived so that whenever $x' > AL$, $P(x > 1) \geq 0.05$. This depends only upon the uncertainty in the sampling and analytical processes, and not on the intrinsic variability of the workplace (GSD in our model). Thus, the OSHA action level plots as a vertical line in the (e, GSD) plane.

The statistically derived NIOSH action level uses a significantly different null hypothesis. The null hypothesis is that the measurement was collected from an environment where no more than 5% of all exposures exceed the standard. Thus, the AL is derived so that whenever $x' > AL$, $P(e \geq 0.05) \geq 0.05$. This decision actually compensates for the uncertainty of the measurement process and tests for the intrinsic variability of the work environment, so the AL is a strong function of GSD.

We are introducing a new statistically derived concept called the average exposure limit action level (AEL AL). This decision threshold is designed to test the null hypothesis that the long-term average exposure is less than the 95% of the standard. Thus, the AL is derived so that whenever $x' > AL$, $P(\bar{x} > 0.95) \geq 0.05$. Since $\bar{x}$ is a function of the intrinsic variability of the workplace, the AEL AL is a strong function of GSD.

Finally, we come to the Legal action level which for purposes of illustration is shown with a value equal to half the standard. It is more stringent than OSHA and less stringent than either the NIOSH or the AEL action level criteria. We have not found a clear statement of the hypothesis which it tests, but it is included here since it is in use. If we were to cast its null hypothesis in terms similar to those used in the OSHA criteria, we would say that the Legal AL is derived so that whenever $x' > AL$, either $P(x \geq 1) > 0.00001$ or $P(x > 0.60) \geq 0.05$. In this context, the Legal AL either requires 95% confidence that the measured exposure is less than 60% of the PEL or 99.999% confidence that it is less than the PEL. Note the subtle creation of a new PEL by the Legal AL!

DECISION REGIONS FOR WORKPLACES WHICH ARE OK:

Figure 6 shows the decision regions for the OSHA action level test. There are four regions shown. Recall that there are three possible outcomes from the generalized action level decision criteria. Those workplaces which lie in

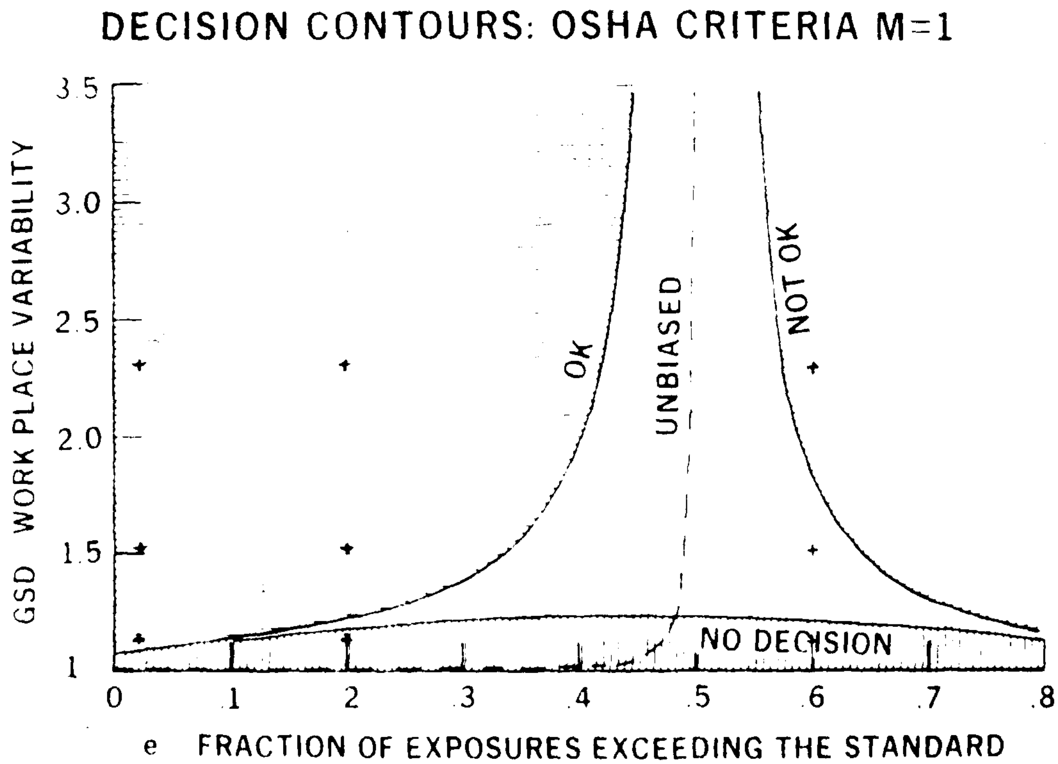

Figure 6. Decision regions showing which workplaces are likely to pass or fail the OSHA decision criteria when a compliance officer makes one measurement and requires 95% confidence that the actual exposure exceeded the standard using a sampling method with a coefficient of variation of 10%.

an area where one outcome occurs with a probability greater than 0.5 have been shaded. Horizontal lines indicate OK, diagonal lines indicate NOK and vertical lines indicate no decision is likely. The unshaded region includes those workplaces where the three outcomes are approximately equally likely in that no one of them occurs with a probability greater than 0.5. The dotted line, called the unbiased decision contour, identifies those workplaces for which P(OK) = P(NOK). This could be thought of as the boundary of acceptable workplaces, but the P(OK) is so small along this boundary that it seems more appropriate to choose the boundary of the horizontally shaded area where P(OK) = 0.5 as the defined edge of the acceptable region. Once again, we are face-to-face with the difficulty of defining exactly what an acceptable workplace is.

However, if you will accept our definition and refer back to Figure 4, you will see that the OSHA criteria is likely to accept some workplaces which we had previously agreed were unacceptable.

Figure 7 shows the decision contour for the Legal action level criteria. Although it is clearly more stringent than the OSHA criteria of Figure 6, it still accepts some workplaces which we agreed to reject in Figure 4.

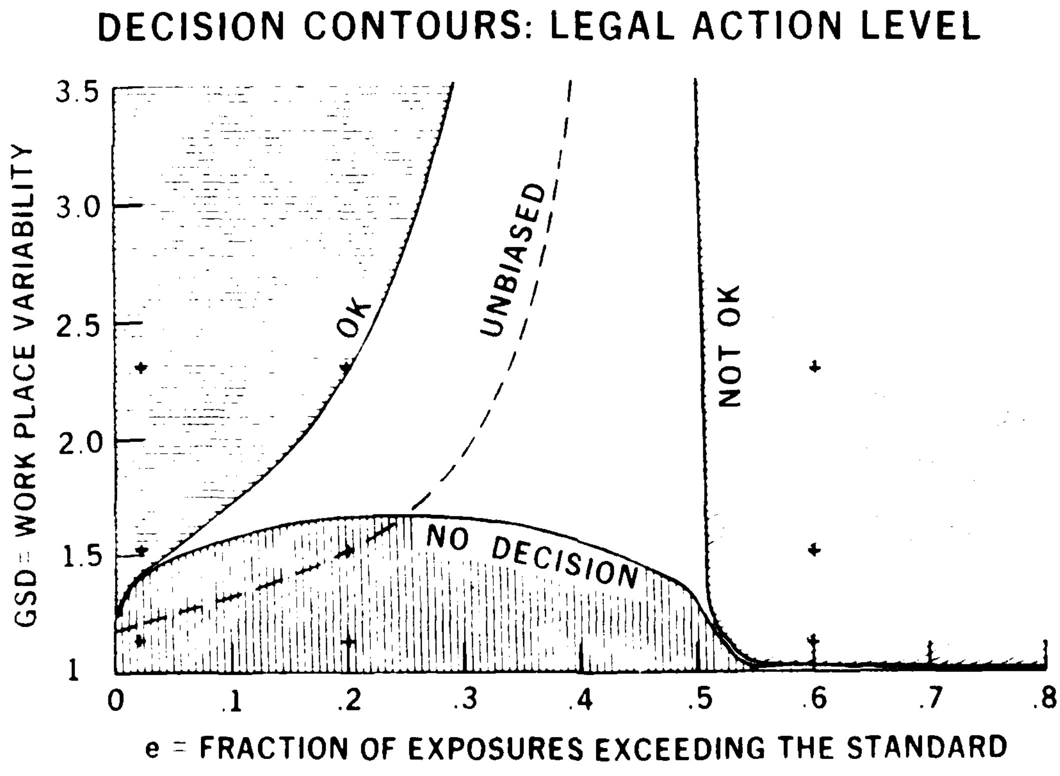

Figure 7. Decision regions showing which workplaces are likely to pass or fail the Legal action level criteria when 0.5 = AL/PEL.

At this point, we have seen that decision criteria which ignore the variability of a workplace tend to be very lenient with highly variable workplaces. Recall from Figure 5 that the action levels in the NIOSH and the AEL criteria are strong functions of workplace variability. As you might expect. they do not favor the highly variable workplaces.

Figure 8 shows the decision contours for the NIOSH action level. There are almost no workplaces clean enough to pass this test. Only those right along the GSD axis with fewer than one exposure per year above the standard will pass this test. By far, the most significant feature of this decision criteria is the large number of workplaces for which no decision is the most likely outcome.

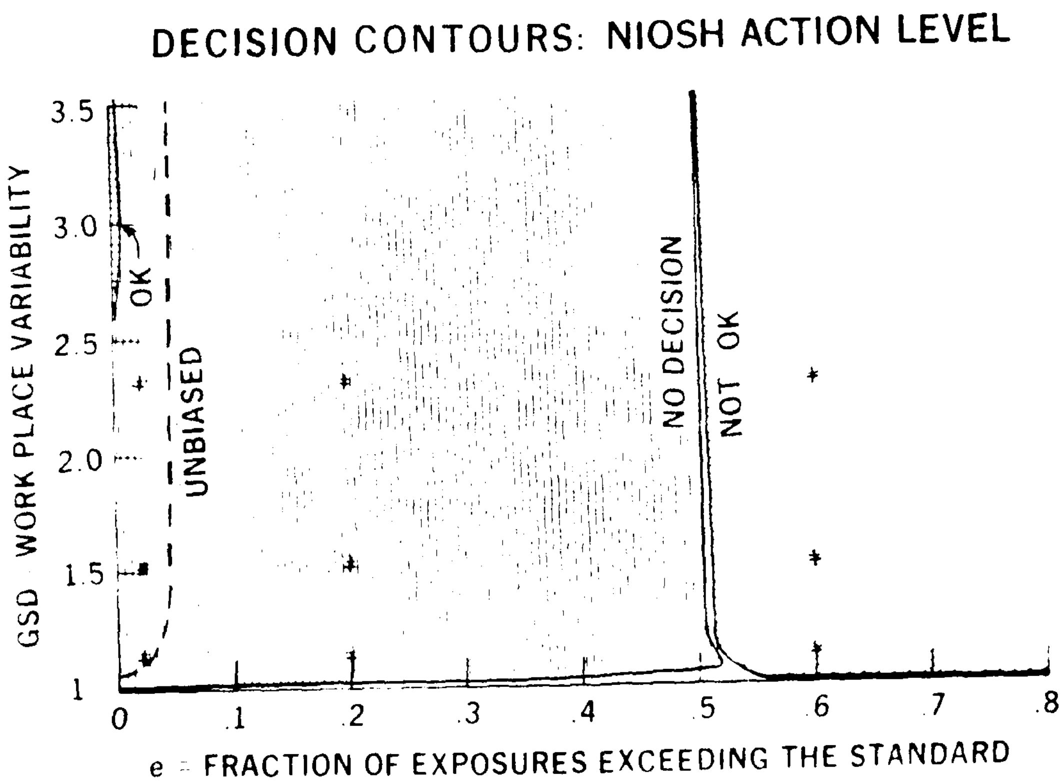

Figure 8. Decision regions showing which workplaces are likely to pass or fail the statistically derived NIOSH action level criteria based upon 95% confidence that no more than 5% of all exposures exceed the PEL.

Figure 9 shows the decision contours for our proposed AEL action level decision criteria. Although it is more lenient than the NIOSH AL criteria, there are still not very many workplaces which can pass this test.

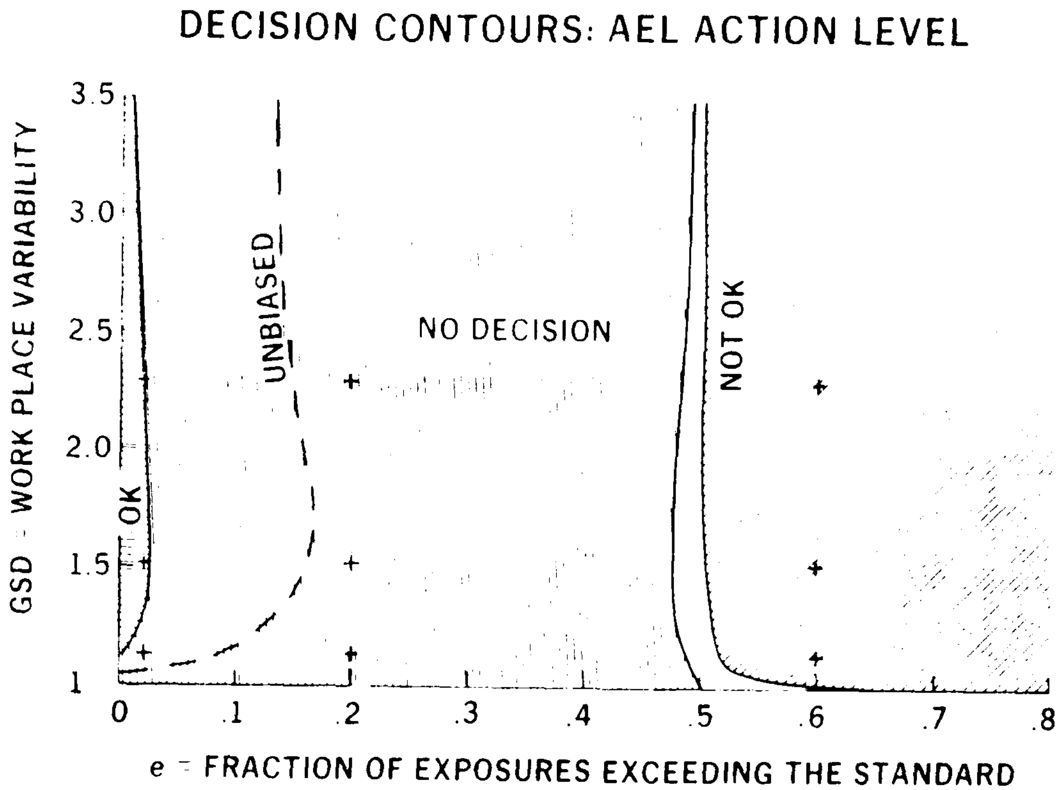

Figure 9. Decision regions showing which workplaces are likely to pass or fail the statistically derived average exposure limit (AEL) action level criteria based upon 95% confidence that the long-term average exposure is less than 95% of the PEL.

A CANDIDATE REPLACEMENT FOR EXCURSION FACTORS:

Having now shown which workplaces pass the action level test for four different null hypotheses, it is time to turn to another question of industrial hygiene significance. What is the maximum probable exposure likely to be experienced by an employee working in a workplace which has passed the test? We already saw that both the OSHA action level and the Legal action level are likely to accept some workplaces with high GSD and with MPEs greater than four times the standard. We have not yet examined the NIOSH or the AEL criteria to determine the extreme exposures they are likely to permit.

Figure 10 shows the MPE as a function of GSD for the dirtiest workplace which passes each action level test. This chart shows clearly that both the OSHA action level and the Legal action level test are likely to accept environments with very high maximum probable exposures. In contrast, both the NIOSH and the AEL action level criteria show an upper limit on the MPE for the workplaces which they are likely to accept. The NIOSH action level is seen to be extremely restrictive for workplaces with medium to large variability, while the AEL action level seems to be more evenhanded in those cases.

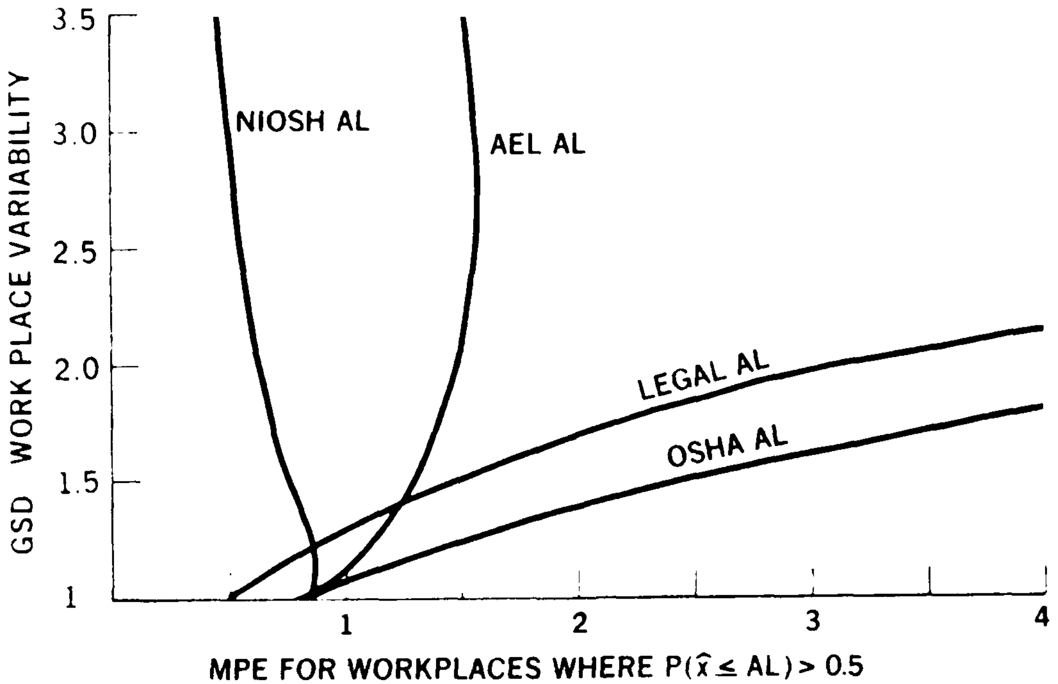

Figure 10. The maximum probable exposure (MPE) is plotted as a function of workplace variability (GSD) for the dirtiest workplace likely to pass each of the four action level decision criteria.

In fact, because of the way it was constructed, the upper limit of the maximum permissible exposure for the AEL test is 1.64 times the ratio of the AEL to the PEL, and it occurs at a GSD = 1.75. Thus, in Figure 10 where the AEL is 95% of the PEL, the upper limit of the MPE for workplaces likely to pass the test is (0.95)(1.64) = 1.56 times the PEL. The long-term average exposure for this workplace (e = .021, GSD = 1.75) is $\bar{x}$ = 0.37 or 37% of the standard.

An Average Exposure Limit action level decision threshold set equal to 95% of the Permissible Exposure Limit is less restrictive than the original statistically valid NIOSH Action Level. It therefore accepts a larger number of workplaces than the earlier test. Further, the maximum probable exposure for a workplace passing the AEL AL test equals (1.64) (AEL/PEL), so it is possible to control both the average exposure and the maximum likely exposure by selecting the ratio of AEL to PEL. Finally, considerable professional judgement is required to properly implement the AEL AL decision criteria, since the workplace variability (GSD) must be estimated separately from the measurement used to determine workplace quality.

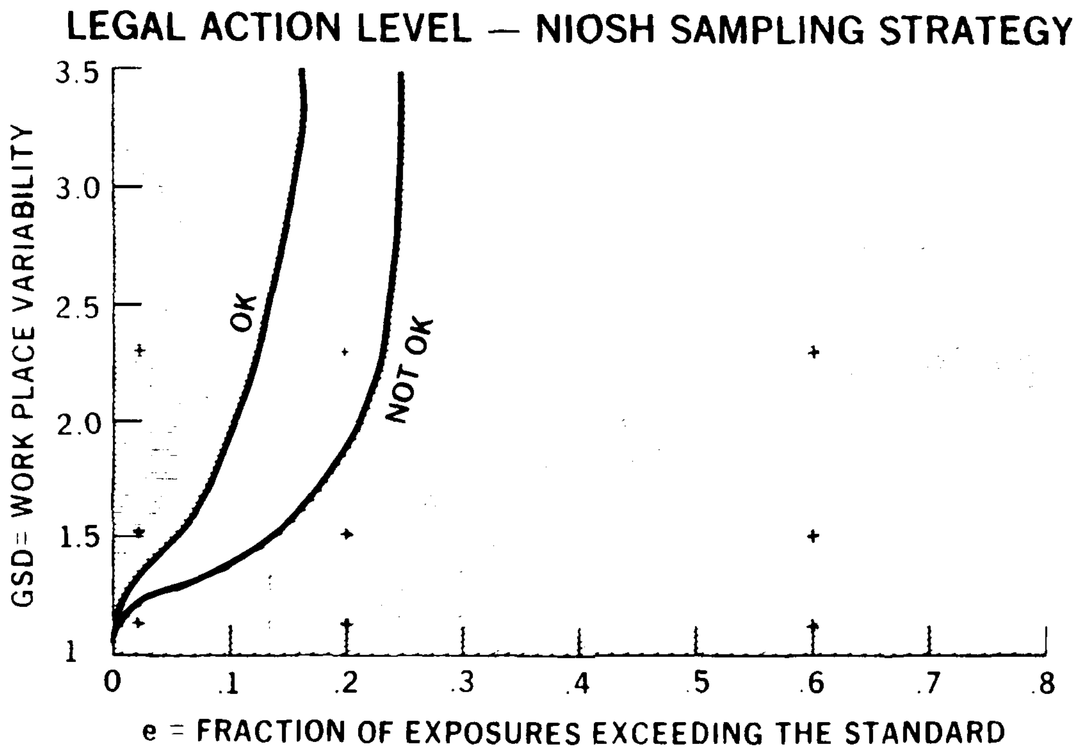

Figure 11. Decision regions for the two-measurement NIOSH Sampling Strategy using the Legal action level (AL/PEL = 0.5) decision threshold. Note the absence of the no-decision region which is so prominent in Figure 7 where the single-measurement Legal action level test is used.

INTERPRETATION OF MULTIPLE SAMPLES:

All of the decision criteria discussed so far make their decision on the basis of only one measurement. In the case of the AEL and the NIOSH criteria this is a little presumptuous, since one must have an estimate of GSD before applying those criteria but the GSD cannot be estimated from a single sample. In contrast, the OSHA and the Legal decision criteria make no assumptions about the GSD, but the resultant decisions are far too lenient. Therefore, it seems that any decision with statistical validity must be based on several samples.

We now close our discussion with some observations about two widely publicized multiple-sample strategies which we have analyzed.

The first is the NIOSH Sampling Strategy, which one of us discussed at the 1979 AIHC in Chicago (Ref 1). It requires two consecutive measurements, made at least one week apart, to be below the action level in order to decide that a workplace is OK. As a consequence of requiring two in a row to be below the action level it is an extremely conservative test, and many fewer workplaces are accepted by it and many more are rejected by it than by the single measurement decision criteria which are the main topic of today's paper. Compare Figures 11 and 12 with Figures 7 and 8, to see the difference between the two-sample strategy and the single sample decision criteria for the Legal action level and the NIOSH action level, respectively.

The second is the OSHA compliance strategy. It is our understanding that the Industrial Hygiene Field Operations Manual instructs compliance officers to collect as many breathing zone samples as can reasonably be expected to be independent of one another during a survey. These samples are prioritized in the order of expected concentration on the basis of professional judgement, and the laboratory analyzes them in that priority order. Any sample found above the upper action level constitutes grounds for a citation, if OSHA chooses to issue one (Ref 2).

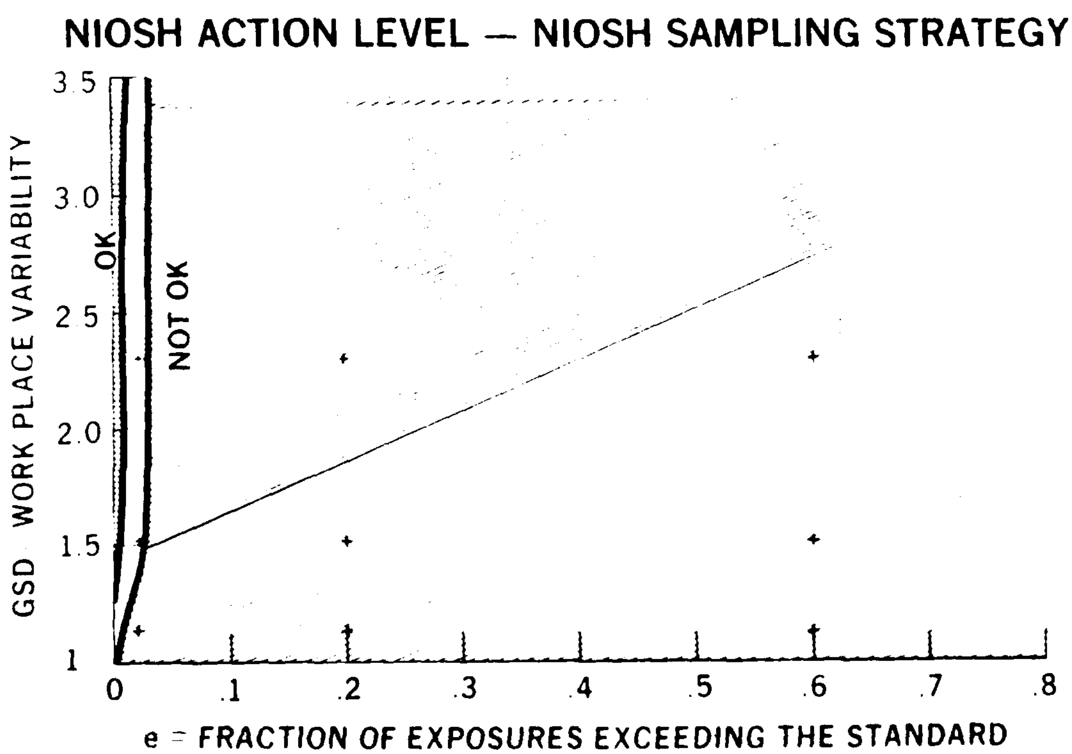

Figure 12. Decision regions for the two-measurement NIOSH Sampling Strategy using the NIOSH action level decision threshold. Compare with single-measurement NIOSH action level test of Figure 8.

If m samples are collected and all are drawn from the same distribution of exposures, then a workplace will be accepted if all m measurements lie below the action level. If P(OK) is the probability that one sample is less than the action level, then $(P(OK))^m$ is the probability that all m measurements are below the action level. Since P(OK) is a fraction less than one, the probability of accepting a workplace decreases exponentially with the number of statistically independent measurements a compliance officer is able to make. In fact, by taking as few as 14 samples, a compliance officer can reduce the size of the acceptable region in the (e, GSD) plane far enough to exclude eight of the nine workplaces illustrated in Figure 1...and you will recall that in Figure 4 we had tacitly agreed that as many as five of those workplaces were probably acceptable.

Compare Figure 13 with Figure 6 to see the effect of taking six samples.

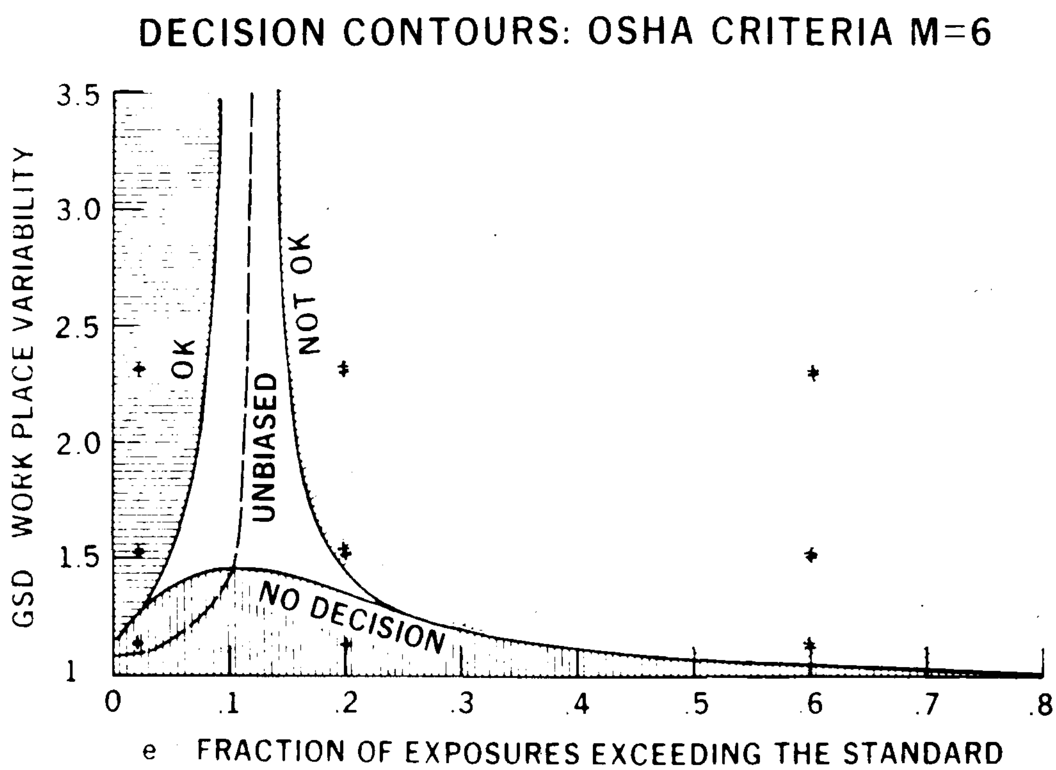

Figure 13. Decision regions for the six-sample OSHA Compliance Strategy. Compare with the single-sample OSHA Compliance Criteria of Figure 6.

CONCLUSIONS:

As shown in Table 3, a viable sampling strategy will have to rely on both "professional judgement" and multiple measurements to come to a valid conclusion about the quality of a workplace.

Table 3

CONCLUSIONS

MULTIPLE MEASUREMENTS ARE MANDATORY FOR STATISTICALLY SOUND DECISIONS

THREE EXPOSURE STANDARDS NEEDED: PEL, STEL, AEL

- (STEL PEL) – DESCRIBES WITHIN DAY VARIABILITY
- (AEL PEL) – DESCRIBES DAY TO DAY VARIABILITY

STATISTICALLY SOUND STRATEGIES ARE ELUSIVE

- SELECTION AND PROPER USE REQUIRES
  - DISCIPLINED PROFESSIONAL JUDGEMENT
- COMPARATIVE STUDY WILL HELP OUR PROFESSION TO DEFINE TWO IMPORTANT TERMS:
  - PROFESSIONAL JUDGEMENT
  - ACCEPTABLE WORKPLACE

Further study is required, but it may be possible to combine an Average Exposure Limit with the Permissible Exposure Limit to replace the now discarded ACGIH excursion factors and to supplement the National Academy of Science emergency exposure limits, which the USAF uses as guidelines during accident recovery operations. The ratio of AEL/PEL could be set to limit the likelihood of unacceptable exposures on unmonitored days the same way the ratio of STEL/PEL limits within day excursions during unmonitored 15 minute periods.

The OSHA implementation of a multiple sample decision strategy is arbitrarily stringent and by design ignores day-to-day variability. It is therefore not suitable for general use by industrial hygiene professionals other than OSHA compliance officers.

The NIOSH implementation of a sequential sampling strategy is also too stringent to be recommended for general use.

Tuggle's one sided tolerance test (Refs 3 and 4), Rappaport's limiting distribution test (Ref 5), Sweet's dynamic programming process (Ref 6), and Roach's nonparametric test (Ref 7) have not yet been evaluated in the general terms reported here.

We recommend that a comparative analysis of which workplaces are accepted by different decision strategies become a part of the formal education of industrial hygienists to provide a modicum of disciplined "professional judgement," even to brand new graduates. Not only will this help them to select the best decision criteria for a given situation, but it will also aid in developing a consensus definition of the term "acceptable workplace."

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